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SOFTWARE TECHNOLOGY FOR ADAPTABLE, RELIABLE SYSTEMS (STARS) PROGRAM

Final Evaluation Report

Contract No. F19628-88-D-0032

Task ID52 – STARS Technology Transfer Demonstration Project for the U.S. Army

Prepared for:

Electronic Systems Center
Air Force Materiel Command, USAF
Hanscom AFB, MA 01731-2816

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13. ABSTRACT *(Maximum 200 words)*
This document presents the final evaluation results gathered from the STARS Technology Transfer Demonstration Project for the U.S. Army. The intent of this demonstration project is to evaluate comparative measures of effectiveness in developing software by using Cleanroom Engineering versus the current software development approaches presently used at Picatinny Arsenal, a DoD software support activity.

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1. Executive Summary

This is a technical report of the results and lessons learned from a STARS sponsored technology transfer demonstration. The Armament, Munitions and Chemical Command Life Cycle Software Engineering Center (AMCCOM LCSEC) at the Picatinny Arsenal was selected as a site to demonstrate that a STARS supported state-of-art software development process, namely Cleanroom Software Engineering (CSE), could be successfully applied in a typical DoD environment. Additionally, the demonstration was viewed as an opportunity to learn more about Technology Transfer in order to support future efforts at other DoD Software Support Activities, such as the one at Peterson Air Force Base.

This report covers the experiences of the 15 month effort from May 1992 through July 1993, but focuses on the period between November 1992 and July 1993 when the selected AMCCOM LCSEC projects were ongoing.

The Picatinny mission is accomplished by both government staff and by supporting contractor personnel. Two demonstration projects were selected: one was performed by government staff and one was principally performed by support contractors. This report reflects principally the experiences gained from the government staff project. Although final results are still somewhat premature, indications are that this project has achieved the following results:

- Cleanroom software engineering practices and process guided program management is a technology that can be successfully transferred to DoD software organizations. Current organizational maturity (e.g. Software Engineering Institute Capability Maturity Model (SEI CMM) Level 1) does not inhibit successful Cleanroom nor process guided technology transfer.

- Picatinny engineering staff productivity and quality was increased while simultaneously increasing job satisfaction with the "team oriented" approach of the Cleanroom practices and process.

- Preliminary findings indicate a return on investment of between 2:1 and 6:1 is possible. A more definitive calculation will be made at project completion.

This 15 month demonstration project identified several "lessons learned" for application to other technology transfer efforts.

- Successful technology transfer programs require five components: (1) formal technology training; (2) formal training in process guided project management; (3) support from reference handbooks; (4) the use of a process support system (e.g. CEPA and its successor); and (5) the availability of qualified follow-on coaching.

- Process-guided project management enhances communications among team members, project members and management.

- Introducing a formal engineering process such as Cleanroom into a DoD organization will require a significant non-recurring investment of time and money. The calculation of the return on investment requires establishment of meaningful before and after metrics of productivity and quality.

This demonstration is an initial fulfillment of the ARPA STARS mission of serving as a catalyst for improving software development in DoD organizational elements. The synthesis of the Picatinny and STARS efforts are realized by the fact that the initial contractor funding for this demonstration project was provided by STARS and Picatinny management has opted to support the continuation of the effort to further evolve their entire organization to use of the Cleanroom technology with their own funds.

Other results include the fact that the IBM STARS team gained actual experience in supporting technology transfer from this effort. There is great excitement in continuing this effort in the future at Picatinny, and using the experiences as a basis to support the demonstration project at Peterson Air Force Base. This project also serves as additional confirmation that Cleanroom software engineering practices are transferrable and effective.

2. Technology Transfer Plan - Overview

The goal for the technology transfer effort for the AMCCOM LCSEC at the Picatinny Arsenal was to conduct a demonstration of CSE practices and process-guided project management (PGPM) at a DoD Software Support Center. The demonstration was to be facilitated by IBM and Software Engineering Technology (SET).

AMCCOM LCSEC was selected in response to their expressed interest in improving the process by which they maintain software in general and, specifically, in using the CSE technology. Additionally, as a typical DoD Software Support Center, it was deemed important to improve the means by which the government spends their largest portion of software money; i.e., in software maintenance (as opposed to new software development).

To conduct the demonstration, both control and demonstration groups were identified. The control group consisted of a sample set of ongoing and completed software projects at the AMCCOM LCSEC. These projects represent the use of "typical" software engineering methods at the AMCCOM LCSEC. Enhancement projects at Picatinny typically include the correction of observed problems, the addition of new capabilities, and in some cases, re-engineering of software. The two demonstration group projects consisted of (1) the Mortar Ballistics Computer (MBC) redevelopment software and M2/3A1 Institutional Conduct of Fire Trainer (I-COFT) software block update. The demonstration aspect of these projects is the adoption of the CSE technology and PGPM techniques as conveyed by the participation of IBM and SET. The hypothesis to be confirmed or rejected in this demonstration was: **The use of CSE practices and process-driven project management improves the effectiveness of the AMCCOM LCSEC in its software support mission on a project basis.** The goal of any software development organization is to develop software, within schedule and budget, that flawlessly performs its mission. Of course, schedule and budget are the constraints established so that the organization contracting for the software solution obtains the software with the minimum possible investment.

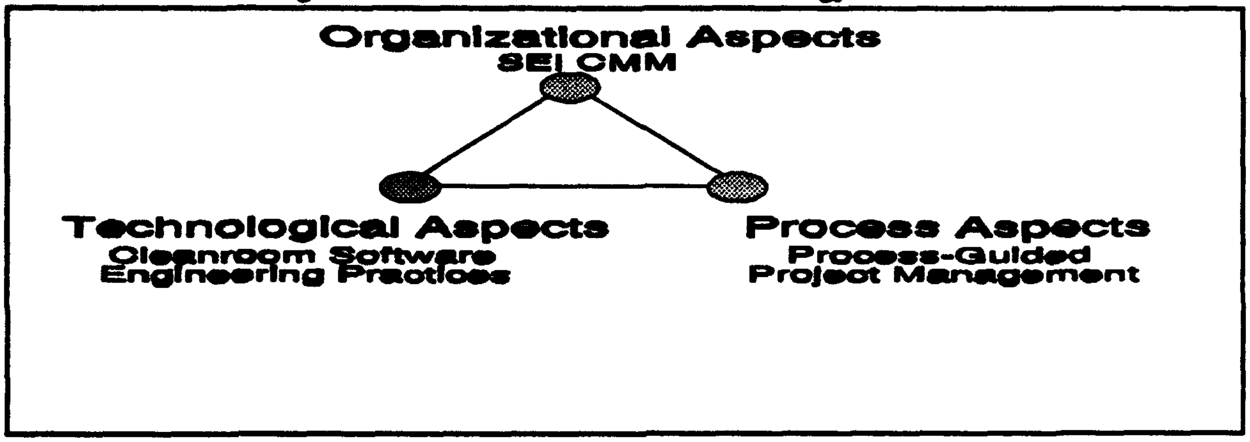
There are three aspects of an organization's behavior that influence how well they can achieve this goal which are represented in Figure 1. The three aspects are:

> Technological aspects - the engineering practices that the engineers utilize to specify, develop and certify the software solution;
>
> Process aspects - the management practices applied by the project in conducting the project; and
>
> Organizational Aspects - the management practices followed by the organization and its organizational culture which serves as the ultimate guidepost to its behavior.

This demonstration project was directed at only changing the behavior in the first two of these three areas by establishing a technology transfer program for the demonstration groups in a two part package which emphasized both the original, disciplined focus of Cleanroom and the

process-guided engineering focus of the IBM STARS team effort. Measures were established to appraise the impact at the project level.

Figure 1: Three Part View of Technology Transfer



In the demonstration project, no overt attempt was made to change or measure any change in organizational behavior or culture. This third part is typically measured by the SEI CMM which focuses on measuring the organization's (not project's) process capability. This three-part focus is depicted in Figure 1. The goal was to establish a "Cleanroom environment" within the demonstration project's organizational structure. A "Cleanroom environment" exists when the objectives and attitudes of an organization foster the proper application of CSE ideas.

Following our experience at Picatinny we believe that if an organization is attempting to improve its behavior in the most efficient manner possible, it should undertake to upgrade all three aspects in a balanced manner so that improvement in each area can feed off of improvements in the other two aspects.

The technology transfer package was implemented in two of the three areas as follows:

(1) the *transfer of Cleanroom Engineering practices* to give team members the technical tools that provide the human behavioral changes necessary to create high quality software with increased productivity, and

(2) the *transfer of process-guided project management* to orient both individuals and teams to thinking and working within a PGPM environment.

The third aspect, *instituting organizational changes* within the scope of the two projects, was not a focus of this initial effort at Picatinny but is discussed since it is a major aspect of organization behavior.

The definition of each of these three aspects and the means by which the technology was transferred for the first two of them is described below. The details of how the technology transfer was implemented is covered in section 4.

In order to transfer the technology, process and culture for a Cleanroom environment, four different tools were employed:

(1) training, in a formal classroom setting which integrated lecture material and numerous hands-on workshops,

(2) coaching, both for project planning and execution as well as a medium to promote ongoing education,

(3) process handbooks, which act as a written source of education material and as a reference during project execution, and

(4) an automated process support system, that enforces process adherence and monitors task completion.

Each of these played a role in the overall technology transfer and often were used together to enhance the effort. Table I summarizes where each technique was used with regard to each aspect of organizational behavior that effects the organization's software engineering maturity.

Table I: Techniques Used in Each Aspect of the Technology Transfer

	Training	Coaching	Handbooks	Automated Support
Cleanroom Software Engineering Practices	X	X	X	
Process-Guided Project Management	X	X	X	X
Organization Management Practices and Culture	NAS	NAS	NAS	NAS

Note: NAS - Not addressed in this study

The sections below provide a more substantive discussion of the three aspects of the technology transfer and a discussion of the means by which the transfer was carried out.

Cleanroom Software Engineering CSE consists of a body of practical and theoretically sound engineering principles applied to the activity of software engineering. Cleanroom consists of a thorough specification phase; resulting in a six part specification, including a precise, **black box** description of the software part of a system. Software development proceeds from the black box specification via a **step-wise refinement** procedure using box-structured design concepts. This process focuses on defect prevention, effectively eliminating costly error removal phases (i.e., debugging) and produces verifiably correct software parts. Development of software proceeds

in **parallel** with a **usage specification** of the software. This usage profile becomes the basis for a **statistical test** of the software, resulting in a scientific certification of the quality of the software part of the system so developed.

Transfer of CSE Technology The transfer of CSE technology was achieved through formal, classroom-style training courses and follow-on coaching of demonstration team members. The courses involved instruction on the underlying specification, development, and certification methods of CSE and included in-class workshops so that students gained experience applying the technology. As often as possible, workshops were held with examples extracted from the I-COFT and MBC projects. Training provided the introduction to and initial experience with the tools that would help enhance individual and team performance.

Project support was given to the team members of both demonstration projects through repeated on-site coaching visits by CSE experts from SET and IBM. This activity helped to solidify the new ideas as team members saw how the techniques were applied to their specific problems.

The major intent of the training and coaching was to establish the human behavioral changes necessary to develop better software. Implementing CSE is an intellectually challenging process that instills specific values into its participants. For example, the focus on product quality, a major Cleanroom theme, instills a "get it right the first time" attitude into the members of CSE teams. As successes are made and milestones conquered, new CSE teams often report significant improvements in job satisfaction, team spirit, and the desire to continue quality improvements. A significant focus of the coaching effort was to positively reinforce each project success in order to create a stronger identity with the project.

Such behavioral changes within a project are improved by active participation from all levels of the organizational hierarchy from contributing technical leads to engineering management. An initial plan was for the project staffs to work closely as teams, rather than as individuals. Additionally, the intention was for the staffs to be motivated and excited about what they were doing; that is, have a strong identity with the process and project. Thus, coaching contained a "cheerleading" aspect, designed to create a healthy Cleanroom environment.

Reinforcement of CSE was provided through the availability of a six volume set of process manuals to the demonstration groups. These process manuals were an integral part of the training program and were discussed in detail, both during the formal training sessions and off-line as a part of the follow-on coaching activities. Their purpose was to augment the training by providing reference information to AMCCOM LCSEC engineers using Cleanroom concepts. They serve as a single reference source for resolving questions about specific issues concerning process adherence.

The process manuals are organized as follows:

- Volume 1: Cleanroom Engineering Process Introduction and Overview
- Volume 2: Organization and Project Formation in the Cleanroom Environment
- Volume 3: Project Execution in the Cleanroom Environment
- Volume 4: Specification Team Practices
- Volume 5: Development Team Practices
- Volume 6: Certification Team Practices

The division of the volumes represents a separation of concerns for the various project stakeholders.

Process-Guided Project Management CSE takes place within a formal process that clearly defines the tasks necessary for the engineering effort to progress, the completion conditions for each task, and the control flow that dictates the order of work on each task. Process-guided project management entails the use of a clearly defined process as the approach to be used to complete the particular project. The intent with process-guided project management is to give engineers a clear and understandable roadmap which they can follow and by which they may track progress towards project completion.

Transfer of PGPM methods Awareness of software process is a key issue in successfully transferring technology to an organization and to an organization's long term success with applying CSE. The project staffs at AMCCOM LCSEC received an introduction to process definition and process guided engineering in the context of CSE. Coaching also reinforced the importance of following the defined process and using the process definition, which defines all of the possible project alternatives, to support the selection of correct project choices.

In addition to training and coaching, the engineering handbooks provided a key reinforcement of the concepts of process-guided engineering. Each volume defines the tasks and the control flow between the tasks necessary to conduct the specific process which is the focus of the manual. Engineering processes are defined as formal control-flow procedures with specific completion conditions. Collections of engineering processes also have the same level of formalized control flow and completion conditions. Thus, each engineer, manager or other staff member has well defined roles and tasks that exist as a part of a larger software process.

The application of the process is supported by formal enactment of the tasks defined in the handbook. For the MBC team, this enactment is automated in the Cleanroom Engineering Process Assistant (CEPA), an automated process support system which has the following mission:

1. To minimize realization productivity losses, which is to reduce the time lost because supporting activities are not properly coordinated. CEPA will significantly improve the probability that all of the pre-requisites, tools and data that an engineer needs to do a task are available with no wasted time on his or her part.
2. To enable engineers to follow the Cleanroom process and thereby obtain all of its benefits.

3. To enforce the Cleanroom process in the most unobtrusive way possible by being user-friendly.
4. To enable all levels of management to plan, schedule and control project tasks and to ensure that the required reviews and verifications take place.
5. To facilitate the collection of all required metrics for providing statistical control of the process and for providing better estimates of development time and cost.
6. To update on-line state data, the data needed to develop the product, and make it immediately available to all members of the project team.
7. To improve formal and informal communication between the members of the group.

The I-COFT team was to practice forms-based enactment, as opposed to the automated enactment using CEPA, so that comparisons could be made about the level of benefit achieved from the tool.

The engineering handbooks, and the two types of enactment give project staff a way to use a project framework (the process model for a project) that facilitates scheduling, task dispatching and task statusing.

Organizational Changes The goal of the demonstration project is not to define a complete organizational assessment model for software engineering. In fact, the SEI CMM adequately performs this for us. The AMCCOM LCSEC organization has undergone a software process assessment, as defined by the SEI, and was assessed to be a level 1 site. The goal of the initial effort is to promote, within the two demonstration projects, enthusiasm for the Cleanroom engineering practices and the motivation to develop high quality software products. The organizational aspects were not a part of the technology transfer, since the focus of the demonstration was to support two projects, not to change the organization.

3. Overview of AMCCOM LCSEC Organization for the Demonstration Project[1]

AMCCOM LCSEC is an SEI CMM level 1 software support site within the DoD that performs software enhancement tasks for a set of Army weapons systems. Much of the enhancement activity is performed by contractors with government oversight. The major product types maintained at Picatinny are fire control systems and training devices. The maintenance projects for these products are typically software block updates (SBU). SBU's are an accumulation of change requests from the customer, to be delivered normally within 12 to 18 months.

The desire for CSE technology was a result of the recognition by AMCCOM LCSEC management that the software process was not under intellectual control. Each new software project, whether performed by contractors or civil servants, was treated largely as new activity that did not necessarily draw on prior experience for process improvement. The only factor that perpetuated experience was people, be it government or contractor, who participated in the same projects time after time. Documentation received by Picatinny, when they were given systems to maintain, was poor and no defined process existed for maintaining continual project control. In other words, the state-of-the-practice consisted of classic craft-based software engineering practices that are ad-hoc in nature, as opposed to disciplined software engineering practices. To their credit, this was recognized by the AMCCOM LCSEC management and was the basis for their move to enhance their software engineering capabilities.

Compounding the problem of process immaturity at the AMCCOM LCSEC is the lack of a formal task-oriented planning and/or schedule adherence. Among project staff, formal scheduling and schedule adherence are not emphasized, only that activity on a specific project intensifies as deadlines come close and deliverables are imminent. This is an attribute of staff members being spread across a number of projects, with work being driven by the most pressing deadline. In this situation, it is difficult for engineers or team leaders to set up a well defined plan or schedule for solving problems.

The combination of an undefined manner of doing work, along with a lack of task-oriented scheduling created somewhat of a morale problem among software engineers at the AMCCOM LCSEC. They did their work well because of individual skills, but often seemed to be stuck in the same "groove," where the same situations, in terms of schedule, would arise year after year. A general lack of enthusiasm pervaded our initial discussions with project teams.

Despite these difficulties, however, the customers (various users within the US Army) indicate that they are basically content with the quality of the products. This really is a testament to the skill of staff at the LCSEC, where, despite working as a typical DoD Software Support Activity (SSA), they have provided quality work. Not many field reports of failures are submitted by their customers, due to extensive, pre-release usage testing. Unfortunately, evidence suggests that

[1]This overview pertains only to the demonstration projects and not to the Picatinny organization as a whole.

this may be a result of the absence of formal failure observation and reporting mechanisms, making the field quality of AMCCOM LCSEC developed products difficult to ascertain.

AMCCOM LCSEC management recognized the problems with their state of the practice and took the initiative to recognize CSE and PGPM as the mechanisms with which to facilitate the desired cultural, technical and process changes.

The control groups represent the state-of-the-practice at the AMCCOM LCSEC. Baseline metrics were collected in order to gain insight into project practices and to establish a basis of comparison to the demonstration Cleanroom groups. Table II presents the baseline metrics for the control group. Formulas for the measures are defined in Appendix A. These metrics are presented with the caution that some data collection mechanisms are unreliable; resulting in inaccuracies. Specifically, the failure rates of the control group's released software were difficult to find or even non-existent, which may be a result of not having a formal process by which the Army users provide feedback to Picatinny. Pre-Deployment failures are typically not collected in this organization. The numbers in Table II are similar to results reported by Mosemann for other projects within the DoD [Ada and C++: A Business Case Analysis, July 1991].

Table II: Baseline Metrics for Control Group Projects

PROJECT / MEASURE	**All Control Group Projects**	**Only Government staffed Control Group Projects**
Technical staff months	192	135
KLOC (*)	23.14	12.32
Pre-Deployment Failure Corrections	N/A	N/A
Post-Deployment Failure Corrections	N/A	N/A
DERIVED METRICS		
PRODUCTIVITY - LOC/Staff Month	121	91
PRE-QUALITY - Failure/KLOC	N/A	N/A
POST-QUALITY - Failure/KLOC	N/A	N/A

(*) KLOC computed using NASA/Goddard developed lines of code formula of:
(New Lines of Code + 0.2 * Modified Lines of Code) / 1000

4. Technology Transfer/Project Implementation

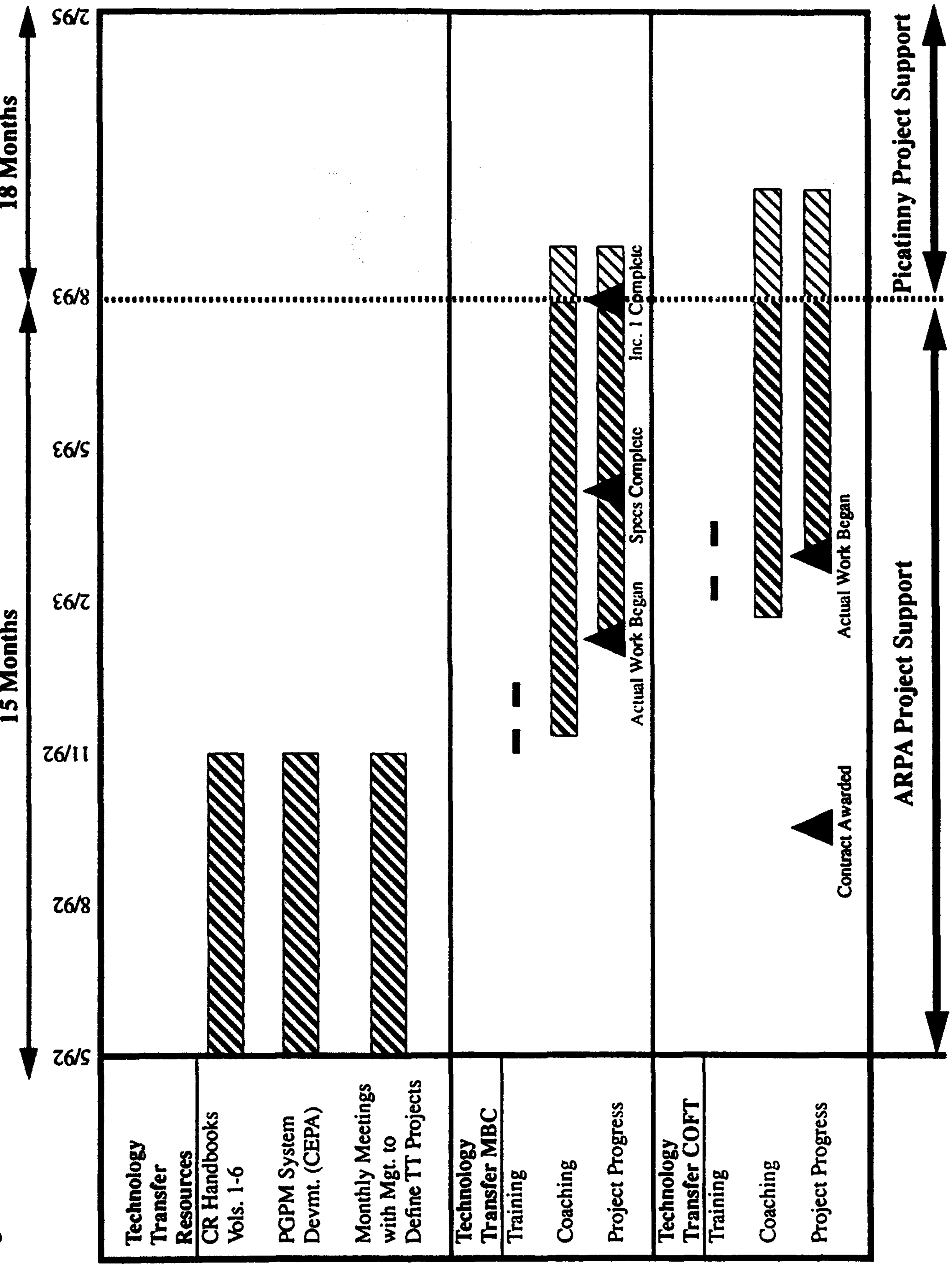
The ID52 task began in late April 1992 and continued until July 31, 1993. The Schedule of Activities (Figure 2) on the next page provides an outline of the chronological relationships between various task activities. The activities include both the technology transfer efforts, and some schedule information for the demonstration projects.

Beginning in April 1992, monthly meetings were instituted with AMCCOM LCSEC management to discuss the transfer of CSE practices and PGPM. Meetings consisted of preparing for the technology transfer, introducing AMCCOM LCSEC management to CSE, and completing tasks to facilitate the technology transfer. During these meetings the two demonstration projects were identified.

In parallel with these meetings, engineering handbooks were prepared and CEPA (Cleanroom Engineering Process Assistant) was enhanced. Other tasks included the preparation of a statement of work which integrated required Cleanroom process aspects, as well as descriptions of the enhancements to be implemented, into a contractor task order. On August 21, 1992, John Foreman, Director of the STARS program participated in a meeting to discuss the interest of STARS in the context of the goals of the Picatinny initiative. At this time, the schedule for the demonstration was established.

The two projects selected for the demonstration of CSE were the M2/3A1 I-COFT and the MBC redevelopment. The M2/3A1 (or Bradley Fighting Vehicle) I-COFT represents a software block update for an application of approximately 200 KLOC Fortran code which controls a gunner/commander trainer for the Bradley Fighting Vehicle. The MBC redevelopment will re-engineer existing mortar ballistics software using the Ada programming language to run on a number of host machine. The I-COFT effort is contracted, with effort monitored by AMCCOM LCSEC staff and the MBC is being redeveloped by government employees. Both project teams received training and engineering handbooks as well as proactive and reactive coaching. The I-COFT team was to practice forms-based enactment, as opposed to the automated enactment of CEPA, so that comparisons could be made to the level of benefit achieved from the tool. The forms-based enactment approach allowed the I-COFT team to use process-guided management principles in planning and delegation of project tasks.

Figure 2: Schedule of Activities



The training program was organized into 2 courses, each of five days duration covering process/specification and development/certification, respectively. The schedule for the training courses was as follows in Table III:

Table III: Schedule of Training

	MBC PROJECT	I-COFT PROJECT
Nov. 2-6, 1992:	Training	
Dec. 6-10, 1992:	Training	
Feb. 22-26, 1993:		Contractor
March 8-12, 1993:	Certification team repeat session	Contractor/Subcontractor
March 17-19, 1993:		Subcontractor
March 25, 1993:		Subcontractor

Perhaps the most effective means of technology transfer is coaching, via both on-site visits and telephone assistance from qualified consultants. When expert engineers exist in software engineering sites, they are used as coaches for others who are learning the new methods. However, when disciplined software engineering is not being practiced, as is the case with Picatinny, the only place to look for qualified coaching is outside.

This aspect of the technology transfer was put into effect with personnel from both SET and IBM at a level of effort of approximately 2 days per week. The effort began in November 1992, and continued until the end of the task. Additionally, staff were always available for telephone support, when a member of IBM and SET staff was not present. A number of other aspects of project support also occurred, which represent a significant portion of the IBM and SET effort, as they formed the basis for the technology transfer.

Table IV: Other Significant Technology Transfer Activities

	MBC PROJECT	I-COFT PROJECT
May 1992:		Example SOW for contractor using Cleanroom delivered
Nov 1992:	Engineering handbooks delivered CEPA delivered	Initial Meeting w/ I-COFT Contractor in Boston
Jan 1993:		Supported software development plan preparation by contractor
Feb 1993:		Manual enactment mechanism delivered to contractor Engineering handbooks delivered to contractor

5. Observations

The following observations are a compilation of SET and IBM experiences with the MBC and I-COFT teams. These observations are in the context of SET's and IBM's other experiences with replacing craft-based practices with engineering-based practices, both in the private sector and with government employees. One must keep in mind these observations are preliminary since the projects have not been completed. These observations are firmer relative to the MBC project team since that project is the farthest advanced.

1. *The assigned project teams were able to assimilate and even adapt the Cleanroom Software Engineering practices.*

A common worry among managers when hearing about Cleanroom is that it is too hard or too mathematical for their staff. At Picatinny, engineers were able to apply and adapt the Cleanroom practices to the needs of their project.

Disciplined engineering in a team environment requires rigor, cooperation of individuals, and the creativity to apply theory to real world problems. This creates a challenging work environment that tends to bring out the best in both individuals and teams.

A prime example of the accomplishments of the MBC team was the tailoring of the box structures algorithm to meet both their application environment and the target programming language Ada. MBC team members have made original contributions to the expression of box structure constructs using the Ada language, which will have applicability across many Cleanroom projects. This has benefitted both the project, in terms of constructive methods, and the individual team members, in terms of a sense of accomplishment. The team has enjoyed using the various Cleanroom techniques and have seen many real accomplishments. The specification team is convinced that this is the most complete and precise specification they have ever written. The step-wise refinement and verification, which drives engineers to define a small step to take at a time, take that step, and then confirm its correctness, has also been successful. The development team is convinced that they have a great design and have minimized the amount of code they need to develop.

Furthermore, as the MBC team have almost completed their first increment, they have already shown major gains in productivity. Early estimates show that productivity has doubled despite the learning curve of working with a new methodology. Moreover, this measure includes time spent toward an entire product specification, which will make future increments less time consuming. Thus, team members are optimistic about continued increases in their productivity (although future predictions can only be assertions and remain to be confirmed at project completion).

2. *Staff morale has improved on the project teams.*

Another common fear of managers when hearing about Cleanroom is that their staffs will not like it due to the rigor of the process and the absence of positive feedback through debugging. It has been our experience at other places where we have introduced Cleanroom. Picatinny is no exception in that when an organization replaces craft-based practices with engineering-based practices, morale improves. The reason seems to be that craft-based practices do not result in a high quality product. When engineers learn to use the Cleanroom practices, they know they can do the quality job they have been striving to achieve.

At the AMCCOM LCSEC all the engineers, both in informal contacts and in a questionnaire distributed to the engineering staff, reported morale improvements. The AMCCOM LCSEC management has also confirmed the existence of the improved morale and, of course, is favorably impressed.

3. *The application of Cleanroom Software Engineering practices and process-guided project management for this project were under the intellectual control of the engineering staff.*

As with any new approach, the intellectual control of the technologies and process reside with the trainers/coaches. As the MBC project started, the transfer of the intellectual control did not shift to the government staff. This was primarily the result of a relatively low level of effort on this project, due to time commitments on other projects. During this time the coaching effort was used primarily to keep the process and practices under intellectual control for the engineering staff, since they did not have time to "make the project their own." Once the level of effort increased for this project, the government staff had the processes/practices and the project completely under their intellectual control, with the coaching providing technical support. As mentioned above, AMCCOM LCSEC staff extended the practices of the concepts to solve their specific problem. They "made the project their own" when they applied the process and practices in the manner they saw correct, while consistent with the principles, to solve their particular project problems. A major lesson is that projects must immediately start using the new approaches aggressively in order to gain intellectual control over the new approaches and the project itself.

4. *Communication among teams (and between team members) is greatly enhanced through process-guided project management.*

An important ingredient of any process-guided activity is communication of contributing teams and individuals. One aspect of this was that no team culture existed at the AMCCOM LCSEC; meaning that no real notion existed of how teams are *supposed* to behave during project execution. This problem manifested itself in many different ways. Testing teams often did not receive specification updates (and failed to ask for them). Also, work tended to be duplicated by multiple team members because the division of tasks was unclear and communication between members occurred too seldom.

There were two aspects of solving this problem at Picatinny. The first was to establish effective communication among team members and the second was to establish communication among the different departments involved in the project. Our observation indicates that communication among team members significantly improved via the team approach and strengthened through the use of CEPA. Team members report that they readily use each other as information sources, quality checks, etc. Team reviews are effective and informative. However, the second aspect, communication between departments, continues to be a problem. The MBC certification team members work for a different department than the specification and development teams. Resulting problems are that the certification team finds themselves working from outdated specifications. Furthermore, the certification team seems to duplicate each other's work. A future goal is to be able to duplicate the success of the specification and development teams in the certification team, primarily by improving communications. A more concerted effort should have been made by the coaches to minimize these communications problems.

5. *The team-oriented approach of CSE saw immediate acceptance and realized both tangible and intangible benefits.*

A key ingredient of Cleanroom is that a team amplifies human performance. The simple idea that many minds are better than one makes the outlook for quality good. However, some less tangible benefits were realized as well. The fact that the entire team is responsible for quality, in a series of checks and reviews, puts pressure on the team and **not** on individuals. This pressure creates a reliance on team activity over individual performance. Furthermore, as successes are encountered, the entire team takes credit, not a single individual; thus, cementing the teamwork concepts. The bottom line is that teamwork improves individual performance.

Our observation is that the MBC team now works within an effective team-oriented environment. We believe that further use of Cleanroom will establish a strong team mentality that will serve to further improve the initial good results.

6. *Coaching is a key ingredient of technology transfer success.*

Although the training was rigorous with a mixture of theory and hands-on workshops, students learn at different rates. Coaching allowed SET and IBM staff to re-educate the slower-to-adopt project staff members and keep the entire team on a common level of knowledge and expertise. IBM and SET technical presence at project inception and during project execution helped solidify the transfer of the technology and ensured that the project got started in the most efficient manner.

Furthermore, there was a gap between the end of training and the start of the project and some of the education was forgotten. Coaching became the mechanism to re-educate and supplement the original training. Further, as good ideas were conceived by some team members, it was possible to see that all members were supplied with the new ideas.

As the project progressed, the CSE ideas needed to be adapted to the specific Picatinny environment. Coaches were used to discuss design alternatives and to help in refining the technology to best serve the application.

Perhaps the most unnoticed but effective use of coaching was in the positive reinforcement the CSE trainers were able to give to the team members and the team as a whole. Coaches are recognized as experts. When experts comment positively on original ideas by a team member, the effect can be enormous in terms of self-esteem and sense of accomplishment and contribution. The CSE trainers tried to positively reinforce those making such contributions and encourage others to seek answers beyond the limits of current knowledge. The "cheerleading" approach increased project satisfaction, which motivated greater project performance.

The idea of coaching with positive reinforcement was first formally tried out by IBM and SET on the Picatinny project based on the hypothesis that it would be helpful in technology transfer. The realized benefits far exceeded our expectations. Based on this experience, it is now believed that coaching should be a formal part of any technology transfer effort.

7. Process-guided project management supports engineers in mastering a new technology.

Process-driven, now referred to as "Process-guided," project management is one of the two basic technologies being advanced by the STARS program. The Picatinny project was the first project on which this key idea has been employed. The MBC project was to utilize an automated system for supporting project process enactment and the COFT project was to utilize manual process enactment.

It was observed that automated process support is quite helpful in supporting technology transfer. This is in spite of some of the shortcomings of the system that the MBC staff was asked to use. The developers of CEPA learned a great deal about how people use such a system; and consequently, requirements for an enhanced process support system were identified and modified. The automated process support system that is to be transferred to Peterson Air Force Base has been improved as a result of this usage.

The reason an automated process support system seems to support technology transfer can be summarized as follows. When doing something for the first time, one often asks, "What do I do next?" or "When will I be done?" This indicates a lack of understanding the big picture, where engineers can clearly place their efforts in a project context. This is not only an attribute of first time usage of techniques or a process, but also an indication that a clearly defined process does not exist or is not effectively managed.

By placing the Cleanroom techniques within a fully defined process, AMCCOM LCSEC engineers knew precisely what step they were currently on, as well as what had been completed and what remained to be done. Giving each individual the foresight that showed where they were in the context of the entire project strengthened project identity and boosted morale.

The results of this project also indicate that experienced engineers will also gain productivity benefits by employing a process support system but that can only be tested by comparing the performance of experienced teams which was not possible at Picatinny.

8. *CEPA, the Cleanroom Engineering Process Assistant, despite some shortcomings, provided valuable process-guidance support for the project.*

There were a number of known, as well as discovered, shortcomings in developing and using CEPA. It was an enhancement of a prototype system first developed during the STARS S Phase. The enhanced system was to provide support to engineers using a specific Cleanroom process model. This approach was known to be somewhat limiting, but was used in order to determine the level of constraint necessary for engineers to easily adopt process guided engineering. Although the engineers did report finding the product constraining, CEPA did allow engineers to identify the tasks assigned to them and locate all files necessary to complete the tasks. Team leaders could also focus their management effort based on assigned/outstanding and completed tasks. This status reporting feature allowed team leaders to manage project tasks at a more reasonable level of granularity, which permitted them to maintain the project under greater intellectual control.

CEPA was viewed as being tightly coupled with the process. As a result, formal training in using it was not given, which would have also made its use more effective. The lack of CEPA training was a significant shortcoming that needs to be rectified in future technology transfer efforts. Additionally, formal training in using the underlying tools in CEPA would have been useful. Other problems with the CEPA implementation used at Picatinny included a clumsy user interface and difficulties in using the software on a network.

The comparison between manual and automated enactment for COFT and MBC respectively, which was an intent of the experiment was also unsuccessful. The reason for this was the significant difference between process models for the two projects. On the other hand, the fact that task statuses were automatically gathered for MBC, through CEPA, was an added convenience.

9. *The insertion of process and technology aspects into a Statement of Work are critical in having contractors use a specified set of ideas to solve problems.*

Aspects of Cleanroom software engineering and process-guided project management were inserted into the statement of work. These aspects defined the content of some of the standard deliverables, which the contractor would prepare for the government. In addition, the Statement of Work communicated the means of support the contractor would have in order to acquire the technologies. Had these aspects not been stated in the Statement of Work, there is little probability that the contractor would have used the Cleanroom concepts. The obvious reason is that no one is "forcing" them to use the ideas. Contractors are typically given a product to build, the definition of a process to follow to build the product is a new perspective. If it is not in the Statement of Work, it becomes a negotiable item.

10. *Specific technological aspects of the Cleanroom software engineering practices were easily and successfully used.*

Using specific techniques are means by which engineers change their behavior and improve their performance. Three techniques in specific were discussed by project staff as being major sources of their improved performance. These techniques are team reviews, Cleanroom specifications and box structured design, and are described in greater detail below:

> **Team reviews**, although experiencing a slow, awkward start, were cited by team members as one of the most successful aspects of the new activity. Members report that the team responsibility/credit eased misgivings about participating in such a big project. This negated "finger pointing" that existed in previous projects and allowed even difficult personality combinations to work together. The result was that everyone participated and worked as a team toward project success and completion. Morale increased sharply as groups of individuals transformed into an effective software team.
>
> **Cleanroom specification**, most notably black box documentation, was cited as being responsible for gains in productivity. Many talented engineers existed on the project and their productivity was significantly enhanced when working from a well defined problem statement. The completeness of the specification was the main reason cited for the team's confidence that they were producing a high quality product.
>
> **Box structured design** is credited with focusing the code generation process and with making team reviews more effective. The team enjoyed the orderly process of developing software. It got them started more quickly on solving a particular problem and they were able to measure the progress of the development activity with more precision than in the past. Since the process relies a great deal on logical thinking as opposed to programming skill, less experienced programmers are able to take a bigger share of the development burden.

6. Conclusions

The most important conclusion noted by this effort, even in its preliminary form, is that the motivation to continue to use Cleanroom practices and PGPM at Picatinny has been established. This demonstration effort was sponsored by STARS and the continued effort is being sponsored by the AMCCOM LCSEC. This result is an instance of the STARS program fulfilling its mission by being the catalyst for introducing improvements to the software engineering capabilities in the DoD. In one sense, that is the most definitive conclusion of this effort; the effort is to be expanded across the entire organization.

In addition to the above mentioned conclusion to this effort, the following seven conclusions can be drawn based on the current status of the MBC and I-COFT projects.

1. *It is possible to transfer CSE practices to project teams operating within a SEI CMM level 1 organization.*

This was shown by the fact that the MBC project has progressed to a point where CSE is being successfully applied. This result shows that a specific maturity rating is not necessary in order to benefit from Cleanroom Software Engineering. The engineering staff also enjoyed using the ideas, and all were interested in using the ideas again. Additionally, nearly all were interested in supporting and participating in the establishment of a "Cleanroom Competency Center" at the Picatinny Arsenal.

2. *SEI CMM level 1 organizations can realize important benefits from the application of CSE.*

This conclusion is supported by the apparent doubling of productivity of the MBC team. Although it is too early to make predictions about quality, the MBC team is excited about the prospect of the upcoming test of their first increment. Thus, any result achieved, whether it be positive or negative, will be viewed by the MBC team as the mark to better on the second increment of this project. The incentive and motivation for continual improvement is firmly in place among MBC team members.

3. *It is possible to transfer PGPM practices to project teams operating within a SEI CMM level 1 organization.*

This was shown by the fact that PGPM has been successfully and enthusiastically applied in the MBC project. Once again, this result shows that a specific process maturity is not a precondition to the successful use of these techniques.

4. *SEI CMM level 1 organizations can realize important benefits from the application of PGPM.*

Two important observations from the MBC project are that (1) PGPM has aided the learning process and helped ease the transfer and application of the CSE technology and (2) following a well defined process significantly improves team productivity.

5. *The return on investment at Picatinny cannot be definitively calculated, but indications are that there is a significant return on investment.*

Since neither project is yet complete, a preliminary estimate of return on investment can only be based on estimates from the information currently available. A detailed analysis appears at the end of Appendix A. The resulting productivity gains and return on investment appear in Table V.

Table V: Projected Productivity Change and Return on Investment (ROI) for MBC

	MBC Project (Not Including Training)	**MBC Project (Including Training)**
Productivity change based on Picatinny baseline	+ 66%	+ 41%
Productivity change based on Picatinny baseline of Government staffed projects only	+ 120%	+ 87%
ROI based on Picatinny baseline	3.31 : 1	2.43 : 1
ROI based on Picatinny baseline of Government staffed projects only	6.09 : 1	5.14 : 1

If these assertions are correct, one must also realize that productivity will increase with the later increments because specifications are complete for the entire system. Once again, the final calculation of return on investment awaits project completion.

6. *A Computer Aided Process Support System (PSS) facilitates technology transfer.*

Automating the non-creative tasks of a new technology, such as file access and simple process flow facilitates the adoption of the new technology. This was true even for a system with limitations known and subsequently observed in CEPA. CEPA's successor system (being developed for deployment on the Air Force demonstration project) applies many of the lessons learned from observing CEPA use at Picatinny.

7. *Based on this demonstration we now believe that a technology transfer program to support individual projects at a level 1 organization should consist of the following five components: (1) formal CSE training, (2) training in PGPM, (3) the availability of engineering handbooks, (4) the use of a PSS (e.g., CEPA and its successor), and (5) the availability of qualified coaching.*

The combination of technology transfer components created a series of successes at Picatinny; including productivity gains, expected quality gains, and the increased motivation of the engineering staff.

The MBC project has realized the most significant gains from the CSE ideas. Once the learning curve had been conquered to the point of useful application, initial successes in creating the Black Box specification served to cement commitment to CSE.

The resulting conclusions from the overall evaluation are preliminary because the demonstration projects are still in their early stages. However, the original hypothesis that Cleanroom improves the effectiveness of the software support activities at Picatinny looks very promising. Indeed, management and staff agree that morale and motivation is extremely high, that teamwork is now the normal mode of operation, and that people are excited about the software process being established and are motivated to produce high quality products.

A good technical road map is in place at Picatinny; the technical personnel are developing the skills that appear to show significant gains in productivity. Even more promising is the fact that these gains were made with minimal exposure to CSE. Future gains are likely to be of greater magnitude as projects are carried out by experienced teams of Cleanroom engineers well advanced on the learning curve.

7. Recommendations

Recommendations based on this work are made in three areas as follows:

1) Actions to support continued process improvement at Picatinny.

2) Actions Peterson Air Force Base can undertake to facilitate their demonstration project.

3) Actions ARPA can undertake to support continued learning for how to best utilize these new software engineering practices to improve the level of software produced by DoD organizations.

Recommendations for Picatinny

Our recommendations for the future of software practices at Picatinny are that CSE should continue to be main-streamed into the process and technology for software engineering. The employment of CSE practices has demonstrated improvements in attitude, competence and process control, which are the building blocks of process maturity and ongoing quality improvement. Picatinny has already taken the necessary steps to continue IBM STARS team support for Cleanroom Software Engineering and Process-Guided Project Management.

Our specific recommendations for Picatinny are as follows:

1. *Picatinny needs to establish a Cleanroom competency group.*

This group should be responsible for continuous review and study of the application of Cleanroom and PGPM at Picatinny. This group's charter should be to internalize and refine CSE and PGPM to the software practices at Picatinny.

2. *The experienced members of the MBC project should establish a training program that supports additional CSE projects at Picatinny.*

The technology transfer package developed by SET and IBM can be used by the trained staff to support additional projects. The MBC team is fortunate to have talented team members who can carry this out.

3. *A program needs to be instituted to upgrade Picatinny's SEI CMM rating to at least a level 3.*

Picatinny is incentivized to move up to a level 3, due to DoD assertions that, at some time in the future, software support activities that function below a level 3 will be closed. In effect, Picatinny, like all other software support activities, must evolve just to stay in business. This step requires a concentrated management effort and commitment to ongoing education and training of Picatinny personnel. Also, new CSE projects should be instituted so that additional

experience can be gained in applying disciplined software engineering and give the opportunity for measurement and improvement. It is our hypothesis that organization process levels can best be improved by a combination of bottom-up improvements resulting from project level work and top-down work with the organization's management. The details of how to do this at Picatinny will need to be developed.

4. *Organize the transfer of the Process Support System (PSS) being developed for the Air Force demonstration project to Picatinny.*

The understood and observed shortcomings in CEPA are primarily addressed by the PSS being developed by the IBM STARS team for use on the Air Force Demonstration Project at Peterson Air Force Base. The major source that provided input to the specification process for the PSS was the experience gained by using CEPA at Picatinny. As a result, many of the improvements desired by Picatinny are being developed as a part of the PSS. The PSS needs to be delivered to Picatinny, as well as to Peterson Air Force Base. As a result, Picatinny will receive their desired functionality and will help provide a second test bed for the PSS.

Recommendations for Peterson Air Force Base

From the perspective of Peterson Air Force Base, the Picatinny experience can be viewed as a "dry run" for the technology transfer process that will occur in Colorado, starting in the fall of 1993. Based on the experiences of the technology transfer effort, a number of recommendations can be made. It should be noted that the experiences and recommendations are independent of project size; the fact that the project at Peterson Air Force Base (PAFB) will be bigger only accentuates the importance of these recommendations. The recommendations are as follows:

1) PAFB and the IBM STARS team need to recognize the three aspects of technology transfer (Organizational, Technological and Process) and consider them when developing the Technology Transfer Plan for the STARS demonstration.
2) The Technology Transfer Plan should entail the five parts of a technology transfer program that were recognized at Picatinny. These parts are:
   a) formal Cleanroom Software Engineering training,
   b) training in Process Guided Project Management,
   c) the availability of engineering handbooks,
   d) the use of a Process Support System (e.g., CEPA and its successor), and
   e) the availability of qualified coaching
3) PAFB and the IBM STARS team need to jointly develop a technology transfer plan that clearly defines:
   a) the technologies to be transferred,
   b) the objectives of the technology transfer effort,
   c) the means by which the technology transfer effort will be measured,
   d) a description of the organization and project on which the technology transfer effort will be conducted, and
   e) the detailed plan of how the technology transfer will be conducted.

This technology transfer plan will eliminate the ambiguities and misconceptions that may exist, by clearly and completely defining what the technology transfer is and how it will be conducted.

4) PAFB will need to create Statements of Work (SOW's) for their contractors that have contained the content of the Technology Transfer Plan. Specifically, the SOW's must define the content of deliverables and the manner in which the work will be conducted, in order to ensure that the Technology Transfer effort is conducted.
5) A Process Support System (PSS) should be used to accelerate technology adoption.
6) The importance of the process management tool on the PSS must be recognized. That tool will give project teams the ability to conduct effective process-guided project management. It should be noted that the shortcomings of the PSS system used at Picatinny are being precluded from the PSS being developed to support the Peterson Air Force Base demonstration.

The Picatinny results should provide reassurance to the Peterson Air Force Base and ARPA managers that three of the technologies (Cleanroom software engineering, process-guided project management, automated process support) the IBM STARS team is recommending for demonstration and refinement at Peterson have a high probability of providing the desired impact. The Picatinny experience has contributed to mitigating the risk of the larger Peterson demonstration, especially since the weaknesses identified at Picatinny in the area of automated process support have been remedied for the Peterson demonstration.

Recommendations for ARPA

This project provides a roadmap for developing the means to support process improvement in DoD software support sites. It is recommended that ARPA support additional technology transfer efforts along the lines taken at Picatinny, in order to leverage the results obtained. Such work will produce tangible returns for the DoD as well as develop a substantial body of knowledge about the best way to improve software engineering processes. The DoD and industry have a desire to have their software engineering organizations operating at a high SEI CMM level of maturity. It is observed that the prevailing belief is that process maturity improvements must be made top down over a long period of time. A working hypothesis is that a combined approach of working from the bottom-up and the top-down can greatly reduce the time and effort required to accomplish a substantial improvement in SEI CMM maturity levels. A program to test this hypothesis and develop the means to implement it would lead to substantial gains for DoD as well as industry in general.

Appendix A - Metrics

Definition and Measurement of Demonstration and Control Group Metrics

The Technology Transfer Plan (submitted to the government as CDRL 05501-001 under task ID-52 on May 6, 1992) defines the set of metrics to be computed on the demonstration and control group projects. This appendix is reproduced and enhanced from that document. These evaluation metrics address productivity, quality and cycle time over accumulations of the projects. Productivity is measured in terms of effort based on reported time by the technical staff. Quality is judged via observed failures/defects in every phase of the development and deployment process. Cycle time is computed based on the duration of the project. A summary of the formulas used to compute each appears below. Refer to the above CDRL for a more complete analysis of the formulas and additional refinements of some of the calculations.

In order to create an appropriate unit of output for a project for the above metrics, a standard for computing lines of code (LOC) has been established. A project is denoted as *i*.

LOC[*i*]=(Num. of New LOC[*i*])+(Num. LOC in Modified Components[*i*])

The lines of code in modified components is necessary due to the maintenance nature of Picatinny enhancement activity. The reason for including an entire modified component is because in Cleanroom, the entire component is analyzed and understood in order to isolate and institute modifications. It is often the case that LOC are reported in thousand units, denoted KLOC or thousand lines of code.

Upon initial work at Picatinny, it was realized that there was a necessity to determine how to factor in changed code, since little code was developed new. As a result, the approach used at NASA/Goddard Space Flight Center was used to measure the effort required to develop changed code. The means used to measure changed code is to determine the number of lines in a changed component, and multiply that by .2. The reasoning behind this is that even though a small part of the component may need to be changed, the full component must be sufficiently read and understood in order to be properly modified. As a result, productivity was measured by the following formula.

LOC[*i*]=(Num. of New LOC[*i*])+(.2*(Num. LOC in Modified Components[*i*]))

Productivity is the rate of output per unit time. In the case of Picatinny, time is measured in staff months.

PRODUCTIVITY=(LOC[*i*])/(Technical Staff Months[*i*])

Quality of a software product is temporal, making it necessary to measure both the pre-deployment and post-deployment quality.

$$\text{PRE-QUALITY-}=(\text{Num. of Pre-deployment Failures}[i])/\text{KLOC}[i])$$

$$\text{POST-QUALITY-}=(\text{Num. of Post-deployment Failures}[i])/\text{KLOC}[i])$$

Cycle time measures project duration in terms of total calendar time elapsed from project inception until project termination. Of course, one needs precise definitions of when to start and stop the clock to compute cycle time.

Return on Investment is a ratio. The ratio is derived from a relationship between the benefit of the use of the factor(s) of the investment and the cost of the investment itself, that is the cost to acquire the factor. Both the benefit and the investment are calculated in dollars. For the Picatinny experiment, one of the results the STARS program desires is the return on investment of acquiring the Cleanroom technologies at Software Support Activities. Stated in terms of a formula:

$$\text{ROI}=\text{BENEFIT FROM INVESTMENT}/\text{COST OF INVESTMENT}$$

This measure of effectiveness is a projection based on a function of the relative changes in terms of productivity, quality and cycle time from the experimental projects, and a projection of the cost to acquire the experimental factor. The cost of investment which represents the cost of the acquisition of the factors. Restating the formula:

$$(12)\quad \text{ROI} = \frac{\text{f(CHANGE IN PRODUCTIVITY, CHANGE IN QUALITY, CHANGE IN CYCLE TIME)}}{\text{COST TO ACQUIRE CLEANROOM TECHNOLOGIES}}$$

Data used for the measurements comes from both off-line and on-line sources. Off-line measures are those that take place on completed projects. Thus, data is gathered, validated and its context re-created so that a basis for comparison can be established. On-line measures are those that take place during project execution. On-line measures are significantly easier to gather and validate since one can prescribe the measures to be made and organize the data to be collected to make the measurement.

Actual Calculation of Projected Return on Investment Based on the Current State of the MBC Project

The following analysis uses only savings and costs from the MBC project to support the technology transfer to both projects. At this time, specifications for the entire MBC system are complete and development for the first increment of code is nearly done. Based on data currently available from discussions with MBC project staff, it is believed that total project effort through first increment certification will total 22.5 staff months (plus 4 staff months of training - two weeks time for 8 people). The MBC project staff believe the first increment will result in 4500 lines of Ada code. Staff productivity is based on 160 hour staff months, with government

employees costing $61 per staff hour. The total amount of IBM STARS team direct project support (training and coaching for MBC) was $43,723.

The results of the calculations appear in Table V.